APPENDIX C

HUMAN HEALTH AND WORKER SAFETY

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This appendix to the Global Nuclear Energy Partnership (GNEP) Programmatic Environmental Impact Statement (PEIS) provides supplemental information pertaining to potential human health impacts associated with radiation exposures, chemical exposures, and worker safety issues related to implementation of the domestic programmatic alternatives.

C.1 RADIOLOGICAL IMPACTS ON HUMAN HEALTH

C.1.1 Radiation and Radioactivity

Humans are constantly exposed to naturally occurring radiation through sources such as the solar system and the earth's rocks and soils. This type of radiation is referred to as background radiation, and it always surrounds us. Background radiation remains relatively constant over time. In addition, anthropogenic (manmade) sources of radiation have been developed since the Industrial Revolution. Manmade sources of radiation include medical and dental x-rays, household smoke detectors, materials released from nuclear and coal-fired power plants, and the residues from atmospheric nuclear weapon testing activities (NCRP 1987). The following sections describe some important principles concerning the nature, types, sources, and effects of radiation and radioactivity.

C.1.1.1 *What Is Ionizing Radiation?*

Atoms lose or gain electrons in a process known as ionization. Ionization results in the formation of an ion pair: the positively charged particle (positive ion) and the negatively charged particle (typically a free electron). Ionizing radiation has enough energy to detach electrons from atoms, creating ions that could cause biological damage (Gollnick 1988). Additionally, when ionization of an atom existing in a molecular chemical bond occurs, free radicals may be formed. These free radicals are highly reactive due to the presence of unpaired electrons (Cember 1996). Although it is potentially harmful to human health, ionizing radiation is used in a variety of ways, many of which are familiar to us in our everyday lives. An x-ray machine is a source of one form of ionizing radiation. Likewise, most home smoke detectors use a small source of ionizing radiation to detect smoke particles in the room's air. Types of ionizing radiation include alpha, beta, gamma, and neutron radiation (Shapiro 1990).

Alpha radiation occurs when a particle consisting of two protons and two neutrons is emitted from the nucleus. Alpha particles, because of their relatively large size, do not travel very far and do not penetrate materials well. Alpha particles lose their energy almost as soon as they collide with anything, and therefore a sheet of notebook paper or the skin's surface can be used to block the penetration of most alpha particles. Alpha particles only become a source of radiation dose after they are inhaled, ingested, or otherwise taken into the body (Shapiro 1990).

Beta radiation occurs when an electron or positron is emitted from an atom. Beta particles are much lighter than alpha particles and therefore can travel faster and farther. Greater precautions

must be taken to stop beta radiation. Beta particles can pass through a sheet of paper, but can be stopped by a thin sheet of aluminum foil or glass. Most of the radiation dose from beta particles occurs in the first tissue they penetrate, such as the skin or tissues of internal organs following intake into the human body (Shapiro 1990).

Gamma and x-ray radiation are known as electromagnetic radiation and are emitted as energy packets called photons, similar to light and radio waves, but from a different energy region of the electromagnetic spectrum. Gamma rays are emitted from the nucleus as waves of pure energy, whereas x-rays originate from the electron field surrounding the nucleus. Gamma rays and x-rays are indistinguishable from each other. Gamma rays travel at the speed of light, and because they are so penetrating, concrete, water, lead, or steel is required to shield them (Shapiro 1990). For example, to absorb 95 percent of the gamma energy from a cobalt-60 source, 2 inches (in) (5 centimeters [cm]) of lead, 4 in (10 cm) of iron, 13 in (33 cm) of concrete or 24 in (60 cm) of water would be needed (USDHEW 1970).

The neutron is another particle that contributes to radiation exposure, both directly and indirectly. Indirect exposure is associated with the gamma rays and alpha particles that are emitted following neutron capture in matter. A neutron has about a quarter of the weight of an alpha particle and can travel 2.5 times faster than an alpha particle. Neutrons are more penetrating than beta particles, but less penetrating than gamma rays. They can be shielded effectively by water, graphite, paraffin, or concrete. For example, to absorb 90 percent of the energy from a neutron source, 10 in (25.4 cm) of water or 12 in (30 cm) of concrete would be needed (Shapiro 1990).

Some elements such as uranium, radium, plutonium, and thorium share a common characteristic: they are unstable or radioactive. These radioactive isotopes are called radionuclides or radioisotopes. As unstable atoms, radioisotopes attempt to reach a more stable configuration by releasing excess energy in the form of ionizing radiation. This radiation can be in the form of particles (e.g., alpha, beta, and neutron) or as electromagnetic energy (e.g., gamma and x-rays). This process is known as radioactive decay. The time it takes to reduce the number of radioactive atoms present to half of the original amount is known as its half-life. Each radioactive isotope has a characteristic half-life. The half-life may vary from a millionth of a second to millions of years, depending upon the radionuclide (Cember 1996).

As a radioactive element emits radioactivity, it often changes into an entirely different element that may or may not be radioactive. Eventually, however, a stable element is formed. This transformation may require several steps, known as a decay chain. Radium, for example, is a naturally occurring radioactive element with a half-life of 1,622 years. It emits an alpha particle and becomes radon, a radioactive gas with a half-life of only 3.8 days. Radon decays to polonium and, through a series of steps, to bismuth, and ultimately to stable lead (USDHEW 1970).

C.1.1.2 *What Are the Units of Radioactivity?*

Scientists and engineers use a variety of units to measure radiation and radioactivity. These different units can be used to determine the amount of radioactivity and intensity of radiation. The curie (Ci) describes the activity of radioactive material. The rate of decay of 1 gram (g) of

radium is the basis of this unit of measure. It is equal to 3.7×10^{10} disintegrations (decays) per second (Cember 1996).

In the International System of Units (SI) the Ci has been replaced by the becquerel (Bq), where:

$$1 \text{ becquerel} = 1 \text{ radioactive decay per second} = 2.7\times10^{-11} \text{ Ci}.$$

The magnitude of radiation exposures is specified in terms of the radiation dose. There are two important categories of dose:

The absorbed dose, sometimes also known as the physical dose, is defined by the amount of energy deposited in a unit mass in human tissue or other media. The original unit is the rad (100 erg/g); it is now being widely replaced by the SI unit, the gray (Gy) (1 Joule/kg), where 1 gray = 100 rad (Cember 1996).

The biological dose, sometimes also known as the dose equivalent, is expressed in units of rem or, in the SI system, sievert (Sv). This dose reflects the fact that the biological damage caused by a particle depends not only on the total energy deposited but also on the rate of energy loss per unit distance traversed by the particle (or "linear energy transfer"). For example, alpha particles do much more damage per unit energy deposited than do electrons. This effect can be represented, in rough overall terms, by a quality factor, Q. Over a wide range of incident energies, Q is taken to be 1.0 for electrons (and for x-rays and gamma rays, both of which produce electrons) and 20 for alpha particles. For neutrons, the adopted quality factor varies from 5 to 20, depending on neutron energy (Shapiro 1990).

The biological impact is specified by the dose equivalent (H), which is the product of the absorbed dose (D) and the quality factor (Q):

$$H = Q\,D.$$

The unit for the dose equivalent is the rem if the absorbed dose is in rads and the sievert (Sv) if the absorbed dose is in grays. Thus, 1 Sv = 100 rem. One rem is roughly the average dose received by an individual in 3 years of exposure to background radiation (NCRP 1987).

C.1.1.3 *How Does Radiation Affect the Human Body?*

Ionizing radiation affects the body through two basic mechanisms. The ionization of atoms can generate chemical changes in body fluids and cellular material. Also, in some cases the amount of energy transferred can be sufficient to actually alter the atom and its chemical bonds, again resulting in chemical changes. These chemical changes can lead to alteration or disruption of the normal function of the affected area.

Potential biological effects depend on how much and how fast a radiation dose is received. Radiation doses can be grouped into two categories, acute and chronic dose.

An acute radiation dose is defined as a large dose (10 rad or greater, to the whole body) delivered during a short period of time (on the order of a few days at the most). If large enough, it may result in effects which are observable within a period of hours to weeks (Blend 1998). However, as in most illnesses, the specific symptoms, the therapy that a doctor might prescribe, and the prospects for recovery vary from one person to another and are related to the age and general health of the individual.

Radiation sickness symptoms are apparent following acute doses greater than 100 rad. Acute whole body doses of greater than 450 rad may result in a statistical expectation that 50 percent of the population exposed will die within 60 days without medical attention (Blend 1998). Exposures to radiation at these levels are quite rare and are almost always due to accidental circumstances.

Blood-forming organ (bone marrow) syndrome (greater than 100 rad) is characterized by damage to cells that divide at the most rapid pace (such as bone marrow, the spleen, and lymphatic tissue). Symptoms include internal bleeding, fatigue, bacterial infections, and fever (Blend 1998).

Gastrointestinal tract syndrome (greater than 1000 rad) is characterized by damage to cells that divide less rapidly (such as the linings of the stomach and intestines). Symptoms include nausea, vomiting, diarrhea, dehydration, electrolytic imbalance, loss of digestion ability, bleeding ulcers, and the symptoms of blood-forming organ syndrome (Blend 1998).

Central nervous system syndrome (greater than 5000 rad) is characterized by damage to cells that do not reproduce such as nerve cells. Symptoms include loss of coordination, confusion, coma, convulsions, shock, and the symptoms of the blood forming organ and gastrointestinal tract syndromes. Scientists now have evidence that death under these conditions is not caused by actual radiation damage to the nervous system, but rather from complications caused by internal bleeding, and fluid and pressure build-up on the brain (Blend 1998).

As a group, the effects caused by acute doses are called deterministic. Broadly speaking, this means that severity of the effect is determined by the amount of dose received. Deterministic effects usually have some threshold level below which the effect will probably not occur, but above which the effect is expected. When the dose is above the threshold, the severity of the effect increases as the dose increases (Cember 1996).

A chronic dose is a relatively small amount of radiation received over a long period of time. The body is better equipped to tolerate a chronic dose than an acute dose. The body has time to repair damage because a smaller percentage of the cells need repair at any given time. The body also has time to replace dead or non-functioning cells with new, healthy cells. This is the type of dose received as occupational exposure. At chronic exposure levels, such as the levels experienced in an occupational or environmental setting, these chemical changes are very small and the body's natural repair mechanisms are able to repair the cell damage before there is a harmful effect. The body has a wide variety of mechanisms that repair the damage induced. However, occasionally, these changes can cause irreparable damage that could ultimately lead to initiation of a cancer, or change to genetic material that could be passed to the next generation. The probability for the

occurrence of health effects of this nature depends upon the type and amount of radiation received, and the sensitivity of the part of the body receiving the dose (Cember 1996).

For low levels of radiation exposure, the probabilities for induction of various cancers or genetic effects have been extensively studied by both national and international expert groups. The problem is that the potential for health effects at low levels is extremely difficult to determine without extremely large, well-characterized populations. For example, to get a statistically valid estimate of the number of cancers caused by an external dose equivalent of 1 rem, 10 million people would be required for the test group, with another 10 million for the control group. This large population is required because the current incidence of cancer is fairly high (approximately 20 percent of all deaths are due to cancer) and the additional risk incurred by low level radiation exposure is low. Also, it is important to account for the many nonradiation-related mechanisms for cancer induction, such as smoking, diet, lifestyle, chemical exposure, and genetic predisposition. These multiple factors also make it difficult to establish cause-and-effect relationships that could attribute high or low cancer rates to specific initiators.

The most significant ill-health effects that result from environmental and occupational radiation exposure are cancer fatalities. These ill-health effects are referred to as "latent" cancer fatalities (LCFs) because the cancer may take many years to develop and for death to occur.

Health impacts from radiation exposure, whether from sources external or internal to the body, generally are identified as somatic (affecting the individual exposed) or genetic (affecting descendants of the exposed individual). Radiation is more likely to produce somatic effects rather than genetic effects. The somatic risks of most importance are the induction of cancers (Cember 1996).

C.1.1.4 *What Are Some Types of Radiation Dose Measurements?*

The amount of ionizing radiation that the individual receives during an exposure is referred to as dose. An external dose is delivered only during the actual time of exposure to the external radiation source. An internal dose, however, continues to be delivered as long as the radioactive source is in the body, although both radioactive decay and elimination of the radionuclide by ordinary metabolic processes decrease the dose rate with the passage of time. The measurement of radiation dose is called radiation dosimetry and is completed by a variety of methods depending upon the characteristics of the incident radiation (Cember 1996).

External radiation is measured as a value called deep dose equivalent. This is defined as the external whole-body exposure dose equivalent at a tissue depth of 1 cm (1000 mg/cm^2). Internal radiation is stated in terms of the committed effective dose equivalent (CEDE), which incorporates a scientific estimate of the dose an individual is "committed" to receive (for up to 50 years for some radionuclides) from radioactive material in the body. The sum of the two contributions (deep dose equivalent and CEDE) provides the total dose to the individual, called the total effective dose equivalent (TEDE). For calculation, regulatory, and recordkeeping purposes, all of the "committed" dose is assigned to the year when intake occurred. Often the radiation dose to a selected group or population is of interest and is referred to as the collective

dose equivalent, with the measurement units of person-rem (Cember 1996). Ten people exposed to 1 rem each would be reported as 10 person-rem.

C.1.1.5 *What Are Some Sources of Radiation?*

Many different sources of radiation have been identified. The majority of the radiation sources are naturally occurring or background sources, which can be categorized as cosmic, terrestrial, or internal radiation sources. Manmade radiation sources include consumer products, medical sources, and other miscellaneous sources. The average American receives a total of about 360 millirem (mrem) per year from all sources of radiation, both natural and manmade (NCRP 1987).

Cosmic radiation is ionizing radiation resulting from energetically charged particles from space that continuously hit the earth's atmosphere. Because the atmosphere provides some shielding against cosmic radiation, the intensity of this radiation increases with altitude above sea level. For example, a person in Denver, CO is exposed to more cosmic radiation than a person in New Orleans, LA. The average annual dose to persons in the United States from cosmic radiation is about 27 mrem. The average cosmogenic dose contribution (mostly due to carbon-14) adds another 1 mrem. Cosmogenic dose is attributable to isotopes that are produced by interaction of cosmic rays with atoms in the earth's atmosphere (NCRP 1987).

Terrestrial radiation is radiation emitted from the radioactive materials in the earth's rocks, soils, and minerals. Radon, radon progeny, potassium, isotopes of thorium, and isotopes of uranium are the elements responsible for most terrestrial radiation. The average annual dose from terrestrial radiation is about 28 mrem, but the dose varies geographically across the country. Typically reported values are about 16 mrem on the Atlantic and Gulf Coastal Plains and about 63 mrem on the eastern slopes of the Rocky Mountains (NCRP 1987).

Internal radiation arises from the human body metabolizing natural radioactive material that has entered the body by inhalation, ingestion, or through an open wound. Natural radionuclides in the body include isotopes of uranium, thorium, radium, radon, bismuth, polonium, potassium, rubidium, and carbon. The major contributors to the annual dose equivalent for internal radioactivity are the short-lived decay products of radon which contribute about 200 mrem per year. The average dose from other internal radionuclides is about 39 mrem per year, most of which results from potassium-40 and polonium-210 (NCRP 1987).

Consumer products also contain sources of ionizing radiation. In some products, like smoke detectors and airport x-ray machines, the radiation source is essential to the operation of the product. In other products, such as televisions and tobacco products, the radiation occurs incidentally to the product function. The average annual dose from consumer products is about 10 mrem (NCRP 1987).

Medical source radiation is an important diagnostic tool and is the main source of exposure to the public from manmade radiation. Exposure is deliberate and directly beneficial to the patient exposed. In general, medical exposures from diagnostic or therapeutic x-rays result from beams directed to specific areas of the body. Thus, all body organs generally are not irradiated

uniformly. Nuclear medicine examinations and treatments involve the internal administration of radioactive compounds or radiopharmaceuticals by injection, inhalation, consumption, or insertion. Even then, radionuclides are not always distributed uniformly throughout the body. Diagnostic x-rays result in an average annual exposure of 39 mrem. Nuclear medical procedures result in an average annual exposure of 14 mrem. It is recognized that the averaging of medical doses over the entire population does not account for the potentially significant variations in annual dose among individuals, where greater doses are received by older or less healthy members of the population (NCRP 1987).

A few additional sources of radiation contribute minor doses to individuals in the United States. The average public dose from nuclear fuel cycle facilities, such as uranium mines, mills, fuel processing plants, nuclear power plants, and transportation routes, is less than 1 mrem per year. Radioactive fallout from atmospheric atomic bomb tests and emissions of radioactive material from U.S. Department of Energy (DOE) facilities contribute less than 1 mrem per year to the average individual dose. Air travel contributes approximately 1 mrem per year to the average dose (NCRP 1987).

C.1.2 How Is Radiation Exposure Regulated?

As described in Chapter 6 of this PEIS, the U.S. Nuclear Regulatory Commission (NRC) would have oversight of any new facility under the domestic programmatic alternatives if the facility is not a DOE operated or DOE regulated facility. The paragraphs below describe the methods that both agencies use to regulate radiation exposure of workers and the public.

The release of radioactive materials and the potential level of radiation doses to workers and the public are regulated by DOE for its contractor facilities. Under conditions of the *Atomic Energy Act* (1954) (as amended by the *Price-Anderson Amendments Act* of 1988), DOE is authorized to establish Federal rules controlling radiological activities at DOE sites. The act also authorizes DOE to impose civil and criminal penalties for violations of these requirements.

Occupational radiation protection is regulated by 10 CFR Part 835, Occupational Radiation Protection. DOE has set occupational dose limits for an individual worker at 5,000 mrem per year. Individual DOE sites have set administrative control levels at a fraction of this dose limit to help enforce the goal to manage and control worker exposure to radiation and radioactive material to a level as low as reasonably achievable (ALARA).

Environmental radiation protection at DOE sites is addressed by DOE Order 5400.5. This Order sets annual dose standards to members of the public, as a consequence of routine DOE operations, of 100 mrem through all exposure pathways. The Order requires that no member of the public receive an annual dose greater than 10 mrem per year from the airborne pathway and 4 mrem per year from the ingestion of drinking water. Similarly, the Radionuclide National Emission Standards for Hazardous Air Pollutants (Rad-NESHAP) (40 CFR Part 61), adopted under the *Clean Air Act* (CAA), limits exposure of an individual member of the public to airborne releases of radionuclides to a maximum of 10 mrem per year.

For commercial facilities, the dose to workers and the public are regulated by the NRC under the *Atomic Energy Act*, and limitations established by NRC rules are imposed in NRC licenses. Under 10 CFR Part 20, each licensee is required to conduct operations so that the TEDE to individual members of the public does not exceed 100 mrem in a year. Furthermore, 10 CFR Part 20 requires that power reactor licensees comply with the U.S. Environmental Protection Agency (EPA) environmental radiation standards contained in 40 CFR Part 190 (i.e., 25 mrem to whole body, 75 mrem to the thyroid, and 25 mrem to any other organ of any members of the public from the uranium fuel cycle).

C.2 RISK CHARACTERIZATION AND INTERPRETATION OF RADIOLOGICAL DATA

Current DOE guidance (DOE 2002h) for estimating public and worker cancer risk from exposure to ionizing radiation recommends using a conversion factor of 6×10^{-4} fatal cancers per rem, and a factor of 8×10^{-4} per rem for estimating excess cancer morbidity (incidence). Based on this guidance, the probability of an individual worker or member of the public contracting a fatal cancer is 6×10^{-7} per mrem. These conversion factors are based on a technical report issued by the Interagency Steering Committee on Radiation Standards. In this PEIS, only fatal cancers are presented.

This approach estimates excess cancer fatalities (i.e., those above the naturally occurring annual rate). The current national rate of deaths from cancer is 171.4 per 100,000 people annually (Ries et al. 2003). Estimates of expected LCFs from radiation exposures are calculated from the effective dose equivalent, which weights the impacts on particular organs so that the dose to different organs (i.e., in the body, different radionuclides can affect different organs) can be compared. All doses in this PEIS are effective dose equivalent unless otherwise noted.

Sometimes calculations of the number of excess cancer fatalities associated with radiation exposure do not yield whole numbers and, especially in regard to public exposure from normal operations, may yield numbers less than 1.0. For example, if a population of 100,000 were exposed to a total dose of only 0.001 rem, the collective dose would be 100 person-rem, and the corresponding estimated number of cancer fatalities would be 0.06 (100,000 persons × 0.001 rem × 0.0006 cancer fatalities/person-rem = 0.06 fatal cancers).

A fractional cancer fatality estimate, such as 0.06, should be interpreted as a statistical estimate. That is, 0.06 is interpreted as the average number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. In most groups, no person (0 people) would incur a cancer fatality from the average 0.001 rem dose each member would have received. In a small fraction of the groups, one fatal cancer would result; in exceptionally few groups, two or more fatal cancers would occur. The average number of deaths over all the groups would be 0.06 fatal cancers (just as the average of 0, 0, 0, and 1 is 1/4, or 0.25). The most likely outcome is 0 cancer fatalities.

These same concepts are assumed to apply to estimating the effects of radiation exposure on a single individual. Consider the effects, for example, of exposure to background radiation over a lifetime. The "number of cancer fatalities" corresponding to a single individual's exposure over a (presumed) 70-year lifetime to 0.3 rem per year is the following:

1 person × 0.3 rem/year × 70 years × 0.0006 cancer fatalities/person-rem
= 0.013 cancer fatalities

This could be interpreted that the estimated effect of background radiation exposure on the exposed individual would produce a 1.3 percent chance that the individual might incur a fatal cancer caused by the exposure.

C.3 RISK ESTIMATES AND HEALTH EFFECTS FOR RADIATION EXPOSURES TO WORKERS

For the purpose of evaluating radiation exposure, workers may be designated as radiation workers or general employees (based upon the potential level of exposure they are expected to encounter in performing their work assignments), or as visitors. Within a given worker population, collective dose data are presented in units of person-rem. The average radiation dose to this worker population can be calculated from this collective dose by simply dividing the collective dose (person-rem) by the number of workers (persons).

Radiation workers are those employees whose job assignments place them in proximity to radiation-producing equipment and/or radioactive materials. These workers are trained for unescorted access to radiological areas. These workers are assigned to areas that could potentially result in them receiving an annual TEDE of more than 100 mrem per year. All trained radiation workers wear dosimeters. Dosimeters are radiation detection devices used to record the external radiation dose received by the wearer. The primary type of dosimeter used to measure occupational radiation dose is the thermoluminescent dosimeter (TLD) (Shapiro 1990). TLDs are processed on a routine basis; however, they may be retrieved for special processing more frequently if necessary. TLDs are sensitive to beta, gamma, and in some applications, neutron radiation. Personal exposure records are maintained for all monitored radiation workers to ensure personnel doses are maintained within regulatory limits and to track radiation exposure over time. Other types of dosimeters such as extremity dosimeters (for monitoring dose to areas of the body such as hands and arms) or neutron dosimeters may be worn when circumstances warrant.

For DOE facilities, potential exposure to radiation is controlled by limiting access to areas where radiation or radioactive materials may be present. These areas are characterized to determine their potential radiation hazard and are posted as one or more of the following, as applicable (10 CFR Part 835):

- **Controlled area:** Any area to which access is managed by or for DOE to protect individuals from exposure to radiation and/or radioactive material.
- **Airborne radioactivity area:** Any area, accessible to individuals, where:
    - The concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the derived air concentration (DAC) values listed in 10 CFR Part 835.
    - An individual present in the area without respiratory protection could receive an intake exceeding 12 DAC-hours in a week.

- **Contamination area:** Any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed the removable surface contamination values specified in Appendix D of 10 CFR Part 835, but do not exceed 100 times those values.
- **Radiation area:** Any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 0.005 rem in 1 hour at 12 in (30 cm) from the source or from any surface that the radiation penetrates.
- **High radiation area:** Any area, accessible to individuals, in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 0.1 rem in 1 hour at 12 in (30 cm) from the radiation source or from any surface that the radiation penetrates.
- **Very high radiation area:** Any area accessible to individuals in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads in 1 hour at 3.3 feet (ft) (1 meter [m]) from a radiation source or from any surface that the radiation penetrates.

NRC requirements for posting and access control for radiological areas are contained in 10 CFR Part 20, and are similar to the DOE requirements in 10 CFR Part 835.

General employees are those employees who are not currently trained as radiation workers but whose job assignment may require their occasional presence within a controlled area with an escort. They may be exposed to transient radiation fields as they pass by or through a particular area, but their job assignments are such that annual dose equivalents in excess of 100 mrem are unlikely.

Visitors are individuals who do not perform routine work at nuclear facilities. They are not trained radiation workers and are not expected to receive 100 mrem in a year. Their presence in radiological areas is limited, in terms of time and access. These individuals generally enter specified radiological areas on a limited basis for walk-through or tours with a trained escort. As appropriate, visitors participate in dosimetry monitoring when requested by the host site.

For facilities under the domestic programmatic alternatives, DOE began by reviewing occupational radiation dose data for currently operating commercial reactors. In 2006, approximately 116,000 individuals working in commercial nuclear plants in the United States were monitored, and approximately 59,000 received a measurable dose (hereafter, workers who received a measurable dose will be referred to as "radiation workers"). During 2006, these radiation workers incurred a collective dose of approximately 11,000 person-rem, which represents a 4 percent decrease from the 2005 value. The average dose to radiation workers was approximately 190 mrem (NRC 2007l). These data were then used, in conjunction with the expected number of employees anticipated to be required to implement the domestic programmatic alternatives, to calculate the collective radiation dose (person-rem) to these employees and the corresponding number of LCFs. Chapter 4 presents the results of this analysis.

For the reference case, this PEIS assumes that all programmatic alternatives could be implemented to achieve a capacity of approximately 200 gigawatts electric (GWe). The nuclear fuel cycles would be different for each of the programmatic alternatives. For example, the No

Action Alternative would produce electricity using light water reactors (LWRs) in a once-through fuel cycle, while the Fast Reactor Recycle Alternative would produce electricity using a mix of LWRs and fast reactors in a closed fuel cycle in which the separated LWR spent nuclear fuel provides the transmutation fuel for the fast reactors.

For all alternatives considered by the GNEP PEIS, existing U.S. enrichment and fuel fabrication capacities would be inadequate to support a capacity of 200 GWe. For all alternatives, existing and planned enrichment and fuel fabrication capacities would need to be increased by nearly 50 percent. In addition to increased uranium fuel fabrication capacity, the Thorium Alternative would also require a fuel fabrication facility for thorium. The closed fuel cycle alternatives (Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative, and the Thermal Reactor Recycle Alternative (all options) would require LWR separation facilities/fuel fabrication facilities. Finally, the Thermal Reactor Recycle Alternative (Option 2) and the Heavy Water Reactor (HWR)/High Temperature Gas-Cooled Reactor (HTGR) Alternative (Option 1—all-HWR) would require one or more facilities to produce heavy water.

C.4 RISK ESTIMATES AND HEALTH EFFECTS FOR RADIATION EXPOSURES TO MEMBERS OF THE PUBLIC

EPA regulations for radionuclides (40 CFR Part 61, Subpart H for DOE facilities) require continuous emission sampling of sources that could potentially contribute more than 0.1 mrem per year effective dose equivalent to an off-site individual from internal and external radiation exposure pathways of released radionuclides. This regulation also sets a limit on the emission of radionuclides that ensures no member of the public receives an effective dose equivalent of more than 10 mrem per year.

For NRC licensed facilities, the NRC regulations in 10 CFR Part 20 limit radiation exposure to individual members of the public to less than 100 mrem per year. The NRC regulations in 10 CFR Part 20 also state that the NRC may impose additional restrictions on radiation levels in unrestricted areas and on the total quantity of radionuclides that a licensee may release in effluents in order to restrict the collective dose. For example, Appendix I to 10 CFR Part 50 states that the calculated annual total quantity of all radioactive material above background to be released from each LWR to the atmosphere will not result in an estimated annual air dose from gaseous effluents at any location near ground level which could be occupied by individuals in unrestricted areas in excess of 10 millirads for gamma radiation or 20 millirads for beta radiation. Similarly, the calculated annual total quantity of all radioactive iodine and radioactive material in particulate form above background to be released from each LWR in effluents to the atmosphere will not result in an estimated annual dose or dose commitment from such radioactive iodine and radioactive material in particulate form for any individual in an unrestricted area from all pathways of exposure in excess of 15 millirem to any organ.

This section discusses the potential impacts to the public from normal operations for each of the domestic programmatic alternatives. Impacts are presented in terms of radiological doses to the public. If more than one facility were to be located on the same site (for example a reactor and a separations facility were colocated), the radiation dose from the entire site would need to be less than the 100 mrem per year standard from 10 CFR Part 20. This means that each individual

facility would have its radionuclide emissions limited to a level that would result in a fraction of the 100 mrem per year standard.

The Clean Air Assessment Package computer code, CAP88-PC Version 2.1 (CAP88) (EPA 2002b) was applied to projected radiological effluents to estimate the potential impacts of airborne radioactive releases from facilities associated with the domestic programmatic alternatives under normal operations. CAP88 is an EPA-approved computer code designed to estimate the effective dose equivalent to the regional human population due to the release of radionuclides from a source. There are three primary pathways for exposure from an atmospheric release of radiological material: ingestion, inhalation, and external exposure. Ingestion would generally be from consumption of plants, animals, fish, or water contaminated with radionuclides. Inhalation could occur if a person were in the path of a radiological plume or from resuspension of previously deposited material. External exposure could occur for people who hunt, fish, or play in areas where the ground or water has been exposed to radiological materials. CAP88 accounts for the various modes of exposure and applies biokinetic models (i.e., the manner in which radionuclides affect various organs of the body) and metabolic parameters (i.e., the typical rates for human body processes) established by the International Commission on Radiological Protection (ICRP).

The effective dose equivalent received by the hypothetical maximally exposed individual (MEI) along with the estimated probability that this dose will result in an LCF are presented in Chapter 4 of this PEIS for the domestic programmatic alternatives. The MEI is defined as a hypothetical individual who, because of proximity, activities, or living habits, could potentially receive the maximum possible dose of radiation or of a hazardous chemical from a given event or process. The collective total effective dose equivalent to the population residing within 50 miles (mi) (80 kilometers [km]) of each postulated facility location along with the calculated number of excess LCFs in this population is also presented in Chapter 4 of this PEIS for the domestic programmatic alternatives.

Public exposures would vary depending on many factors, but would predominantly be affected by prevailing weather patterns and the proximity of the facilities to local population centers. For the domestic programmatic alternatives, as described in Section D.1.6, DOE developed six generic sites to assess the impacts of potential radiological releases associated with normal operations of facilities. These sites provide a range of values for two parameters: offsite (within 50 mi [80 km]) population and meteorological conditions that would directly affect the offsite consequences of radiological releases. The size of the 50 mi (80 km) population has a direct effect on the collective dose received in the area surrounding the site. The environmental concentrations which would result from radiological releases would depend on the meteorological mechanisms of advection and dispersion that a release would experience as it is transported downwind.

The distance to the site boundary was also considered as a site differentiator. This distance affects the dose to the MEI. In general, the greater the distance to the site boundary, the smaller the dose will be to the MEI. DOE obtained information regarding the exclusion distance for all currently operating commercial nuclear power plants in the United States from Appendix A, “General Characteristics and Environmental Settings of Domestic Nuclear Power Plants” in the

Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437 Vol. 2) (NRC 1996). This appendix lists the exclusion distance (km) for every site with an operating reactor.

The mean value for the exclusion distance is 3,018 feet (ft) (920 meters [m]), with a standard deviation of 1,280 ft (390 m). The median exclusion distance is 2,986 ft (910 m). The exclusion distances ranged from a low of 886 ft (270 m) to a high of 6,660 ft (2,030 m). Based on this data, DOE selected the mean distance of 3,018 ft (920 m) as the distance to site boundary for analysis at the generic sites presented in this PEIS. Selection of this mean distance provides an analysis that reflects the expected characteristics of any new commercial nuclear facility and, when combined with the conservatism in the calculation of the quantity of radioactivity released to the atmosphere from these facilities and the conservative assumption that the MEI resides on the site boundary, leads to a calculated radiation dose to the MEI that likely overestimates the dose that this individual would actually be expected to receive.

C.5 HAZARDOUS CHEMICAL IMPACTS TO HUMAN HEALTH

C.5.1 Chemicals and Human Health

Chemicals used in industrial settings are often found in quantities and concentrations that may affect the health of individuals in the workplace and in the surrounding community. The following sections describe both the carcinogenic and noncarcinogenic effects of chemicals on the body and how these effects are assessed.

C.5.1.1 *How Do Chemicals Affect the Body?*

Industrial pollutants may be released to the environment either intentionally or accidentally in quantities that could result in health effects to those who come in contact with them. Chemicals that are airborne, or released from stacks and vents, can migrate in the prevailing wind direction for many miles. The public may then be exposed by inhaling chemical gases, vapors or particles of dust contaminated by the pollutants. Additionally, the pollutants may be deposited on the surface soil and biota (plants and animals) and subsequent human exposure could occur. Chemicals may also be released from industries as liquid waste (effluent) or solid waste and can migrate or be transported from the point of release to a location where exposure could occur.

Exposure is defined as the contact of a person with a chemical or physical agent. For exposure to occur, a chemical source or contaminated media such as soil, water, or air must exist. This source may serve as a point of exposure, or contaminants may be transported away from the source to a point where exposure could occur (AIHA 1998). In addition, an individual (receptor) must come into either direct or indirect contact with the contaminant. Contact with a chemical can occur through ingestion, inhalation, dermal contact, or external exposure. The exposure may occur over a short (acute or subchronic) or long (chronic) period of time. These methods of contact are typically referred to as exposure routes. The process of assessing all of the methods by which an individual might be exposed to a chemical is referred to as an exposure assessment (AIHA 1998).

Once an individual is exposed to a hazardous chemical, the body's metabolic processes typically alter the chemical structure of the compound in its efforts to expel the chemical from the system. For example, when compounds are inhaled into the lungs they may be absorbed depending on their size (for particulates) or solubility (for gases and vapors) through the lining of the lungs directly into the blood stream. After absorption, chemicals are distributed in the body and may be metabolized, usually by the liver, into metabolites that may be more toxic than the parent compound. The compound may reach its target tissue, organ, or portion of the body where it will exert an effect, before it is excreted. The relative toxicity of a compound is affected by the physical and chemical characteristics of the contaminant, the physical and chemical processes ongoing in the human body and the overall health of an individual (AIHA 1998). For example, infants, the elderly, individuals with weakened immune systems and pregnant women are considered more susceptible to certain chemicals.

Chemicals have various types of effects on the body. Generally, when considering human health, chemicals are divided into two broad categories: chemicals that cause health effects but do not cause cancer (noncarcinogens) and chemicals that cause cancer (carcinogens). Note that exposure to some chemicals can result in the manifestation of both noncarcinogenic health effects and an increased risk of cancer (AIHA 1998).

C.5.1.2 *Chemical Noncarcinogens*

Chemical noncarcinogens are chemicals or compounds that when introduced to the human body via ingestion, inhalation, or dermal absorption may result in a systemic effect if the intake exceeds a level that can be effectively eliminated. For example, a noncarcinogenic chemical or compound may affect the central nervous system, renal (kidney) function, or other systems that have an effect on the body's metabolic processes. They may also cause milder effects such as irritation to the eyes or skin, or asthmatic attacks. The levels of the effects are directly related both to the chemical and the level of exposure (AIHA 1998).

For many noncarcinogenic substances, the body is equipped with protective mechanisms that must be overcome before an adverse effect is manifested from a chronic, subchronic, or acute chemical exposure. For example, where a large number of cells perform the same or similar function, the cell population may have to be significantly depleted before an effect is seen. The body can tolerate a range of exposure where there is essentially no change in expression of adverse effects. This is known as the "threshold" or "nonstochastic" concept and has been observed in multiple animal studies. The results of these animal studies are a set of guidelines that serve as the basis for the development of noncarcinogenic toxicity values (AIHA 1998). The No Observed Adverse Effect Level (NOAEL) is the highest exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effect between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered adverse, nor precursors to adverse effects (IUPAC 2007). The Lowest Observed Adverse Effect Level (LOAEL) is the lowest exposure levels at which there are statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group. It is also referred to as the lowest-effect level (IUPAC 2007).

C.5.1.3 *Chemical Carcinogens*

Over the past century, many chemicals have been identified that cause cancer in humans. Examples of these carcinogens include asbestos in insulation, vinyl chloride in the rubber industry, and benzene in solvents. Cancers caused by industrial chemicals can occur in any organ in the body, including the respiratory tract, bladder, bone marrow, gastrointestinal tract, or liver.

Currently, EPA categorizes chemicals as either confirmed human carcinogens, suspected human carcinogens, or confirmed animal carcinogens. For cancer agents (including all radionuclides), EPA provides toxicity information that can be used to determine the probability that cancer may occur. The toxicity factors used to assess exposures to carcinogens are referred to as cancer slope factors (CSFs). The CSFs represent the slope of the dose-response curve from various toxicity studies. Most of the CSFs for nonradionuclides were developed based on the data from chemical-specific 2-year animal studies (ACGIH 1991).

The CSFs for chemicals are the upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. This slope factor is expressed in units of mg/kg-day. Because the slope factors are the 95th percentile upper confidence limit on the probability of a carcinogenic response, the carcinogenic risk estimate represents an upper confidence bound estimate. Therefore, a 5 percent probability exists that the actual risk will be higher than the estimate presented, and the actual risk may well be less than the estimate (EPA 2007g).

C.5.2 How Is Chemical Exposure Regulated?

C.5.2.1 *Environmental Protection Standards*

The Federal Government regulates the exposure to members of the public and the environment from hazardous chemicals through a variety of laws and regulations. Applicable Federal and state environmental acts/agreements include:

- *Resource Conservation and Recovery Act* (RCRA)
- *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) as amended by the *Superfund Amendments and Reauthorization Act* (SARA)
- Federal Facility Compliance Agreements
- *Endangered Species Act*
- *Safe Drinking Water Act*
- *Clean Water Act* (CWA) (which resulted in the establishment of the National Pollutant Discharge Elimination System (NPDES) and pretreatment regulations for Publicly Owned Treatment Works)
- *Clean Air Act* (CAA) (Title III, Hazardous Air Pollutants, Asbestos NESHAP)
- *Toxic Substances Control Act* (TSCA)
- *Federal Insecticide, Fungicide, and Rodenticide Act*

Many of these acts/agreements include environmental standards that must be met to ensure the protection of the public and the environment. Most of the acts/agreements require completed permit applications in order to treat, store, dispose of, or release contaminants to the

environment. The applicable environmental standards and reporting requirements are set forth in the issued permits and must be met to ensure compliance.

The *Emergency Planning and Community Right-To-Know Act* (42 U.S.C. 11001 et seq.), also referred to as SARA Title III, requires reporting of emergency planning information, hazardous chemical inventories, and environmental releases to Federal, state, and local authorities. The annual Toxic Release Inventory Report addresses releases of toxic chemicals into the environment, waste management activities, and pollution prevention activities associated with those chemicals.

DOE Order 450.1 establishes environmental protection program requirements, authorities, and responsibilities for DOE operations to ensure compliance with applicable Federal, state, and local environmental protection laws and regulations, executive orders, and internal DOE policies. The Order specifically defines the mandatory environmental protection standards (including those imposed by Federal and state statues), establishes reporting of environmental occurrences and periodic routine significant environmental protection information, and provides requirements and guidance for environmental monitoring programs (DOE O 450.1).

C.5.2.2 *Regulated Occupational Exposure Limits*

Occupational limits for hazardous chemicals are regulated by the Occupational Safety and Health Administration (OSHA). The permissible exposure limits (PELs) represent the legal concentration levels set by OSHA that are safe for 8-hour exposures without causing noncancer health effects. Other agencies, including the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) provide guidelines. The NIOSH guidelines are Recommended Exposure Limits (NIOSH 2005) and the ACGIH guidelines are Threshold Limit Values (TLVs) (ACGIH 2001). Occupational limits are further defined as time-weighted averages (TWAs), or concentrations for a conventional 8-hour workday and a 40-hour workweek, to which it is believed nearly all workers may be exposed, day after day, without adverse effects. Often ceiling limits, or airborne concentrations that should not be exceeded during any part of the workday, are also specified. In addition to the TWA and ceiling limit, short-term exposure limits may be set. Short-term exposure limits are 15-minute TWA exposures that should not be exceeded at any time during a workday, even if the 8-hour TWA is within limits. OSHA also uses action levels to trigger certain provisions of a standard, for instance appropriate workplace precautions, training, and medical surveillance, for workers whose exposures could approach the PEL (OSHA 2007).

C.6 INDUSTRIAL SAFETY

Worker risks from radiation and chemical hazards are closely controlled by health and safety requirements. In addition to these risks, workers would have the potential for industrial accidents, injuries, and illnesses due to everyday operations. Evaluation of these potential impacts is included in this PEIS.

C.6.1 Regulation of Worker Safety

For NRC-regulated facilities, industrial safety is regulated by 29 CFR Part 1910, Occupational Safety and Health Standards, which identifies such items as occupational health and environmental control, hazardous material control, and personal protective equipment. The requirements contained in 29 CFR Part 1926 define the safety and health regulations for construction activities.

For DOE facilities, DOE Order 440.1B, Worker Protection Management for DOE Federal and Contractor Employees, regulates the health and safety of workers at all DOE sites. This comprehensive standard directs the contractor facilities to establish the framework for an effective worker protection program that will reduce or prevent injuries, illnesses, and accidental losses by providing DOE federal and contractor workers with a safe and healthful workplace. Baseline exposure assessments are outlined in this requirement, along with health and safety responsibilities. 10 CFR Part 851, Worker Safety and Health Program, is applicable to non-federal employees. 10 CFR 851.23 requires that all DOE sites comply with the PELs unless a lower (more protective) limit exists in the ACGIH TLVs.

Safety Programs at DOE facilities implement an Integrated Safety Management System pursuant to DOE Policy 450.4, Safety Management System Policy. The objective of an Integrated Safety Management System is to provide a safe workplace to perform work safely while protecting the worker, the public, and the environment. Integrated Safety Management System principles are the responsibility of line management to ensure safety, competence commensurate with responsibilities, balanced priorities, clear roles and responsibilities, identification of safety standards and requirements, hazard controls tailored to work being performed, and operations authorization.

C.6.1.1 *Construction*

Construction of new facilities or modification of existing facilities would involve risk to workers from accidents or occupational illnesses. These risks could result from construction accidents (e.g., falls and burns), exposure to toxic or oxygen-replacing gases, and other causes. The Bureau of Labor Statistics (BLS) maintains records of total recordable cases (TRC) and cases of lost work days (LWD), which are a measure of work-related injuries or illnesses that include days away from work, restricted work activity, medical treatment beyond first aid, and other criteria. The 2006 nationwide TRC rate published by the BLS for heavy and civil engineering construction is 5.3 per 100 workers and the LWD rate is 3 (BLS 2007b). These values were used to calculate the TRC and LWD incidences for facility construction under the domestic programmatic alternatives.

All of the domestic programmatic alternatives would require a significant amount of new construction in order to achieve the base case nuclear generating capacity of 200 GWe. Although there would be differences among the alternatives in the amount of new construction (i.e., some alternatives would require recycling facilities, others would require support facilities such as a heavy water production facility), these differences would be minor. This is because the construction of approximately 200 GWe of reactor capacity, which is common to all the alternatives, would dominate construction requirements. Consequently, the analysis of worker

injuries and lost work day incidences would be essentially the same for all of the domestic programmatic alternatives. Table C.6.1.1-1 presents these impacts. The construction of these facilities is not expected to introduce hazards in excess of generic construction activities.

TABLE C.6.1.1-1—*Annual Worker Injury and Lost Work Day Incidences for Construction Activities—All Domestic Programmatic Alternatives*

	Total Recordable Case Incidence	Lost Work Day Incidence
Average Annual[a]	239	135
Peak[b]	477	270

[a] Assumes an average annual workforce of 1,000/facility
[b] Assumes a peak annual workforce of 2,000/facility

C.6.1.2 *Operations*

Similar to construction, operation of facilities would involve risks to workers from accidents or occupational illnesses. The 2006 nationwide TRC rate published by the BLS for nuclear electrical generating operations is 1 per 100 workers and the LWD rate is 0.4 (BLS 2007b).

Under the domestic programmatic alternatives, DOE assumes that an additional 1,000 workers would be required for each GWe of new nuclear generation[1] (NRC 2007l). The 200 GWe assumed for the domestic programmatic alternatives results in the estimated total workforce of 200,000 workers. This value, along with the TRC and LWD incidence rates discussed above, was used to project the injuries/illnesses for facility operations under the domestic programmatic alternatives, as shown in Table C.6.1.2-1.

TABLE C.6.1.2-1—*Annual Calculated Nonfatal Total Recordable Cases and Lost Workdays for Operations—All Domestic Programmatic Alternatives*

Number of Workers[a]	Total Recordable Case Incidence	Lost Work Day Incidence
200,000	2,000	800

[a] Assumes 1,000 workers per GWe of nuclear production

[1] In calendar year 2006, the annual collective dose per reactor for LWR licensees was 106 person-rem. This represents a 4 percent decrease from the value reported for 2005 (110). The number of monitored workers refers to the total number of workers that the NRC licensees (who are covered by 10 CFR Part 20) reported as being monitored for exposure to external and internal radiation during the year. This number includes all workers for whom monitoring is required and may include visitors, service representatives, contract workers, clerical workers, and any other workers for whom the licensee determines that monitoring devices should be provided. Between 2000 and 2006, a range of 105,000 to 116,000 workers at the 104 LWRs were monitored for exposures. This equates to approximately 1,010 to 1,115 workers per reactor. For purposes of the PEIS analysis, it is assumed that approximately 1,000 workers would be required for each GWe of reactor capacity.

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